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Transient Stability and Fault Current Reduction of SPP with Bi-2212 SFCL Considering Recovery Time

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Abstract

This paper presents the recovery time characteristic of BSCCO (Bi-2212) Superconducting Fault Current Limiter (SFCL) on Small Power Producer (SPP) for transient stability and fault current reduction. The Bi-2212 SFCL thermal model including the resistance behavior is investigated to determine the recovery time characteristic on the transient stability. The recovery time of the SFCL is directly obtained by adjusting the shunt reactor to demonstrate the effect of the SFCL recovery. The simulation results reveal that the recovery time of the SFCL depends on the shunt reactance. With the high shunt reactance, the SFCL can more diminish the fault current than the one from the low shunt. Nevertheless, the stability margin will be decreased leading to the out of step condition of generator. For this reason, this paper also proposes the method to find the suitable shunt reactance of the SFCL to accomplish both the transient stability and fault current curtailment.

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Keywords: Small Power Producer (SPP), Superconducting Fault Current Limiter (SFCL), BSCCO, Transient Stability.

1. Introduction

Nowadays, with augmentation of industrial and economic expansion, electrical power generation systems are increasingly progressed for the demand and to supply the future load sufficiently. Therefore, numbers of power producers are instantly developed to fulfill this requirement such as Small Power Producer (SPP) and Very Small Power Producer (VSPP). However, if the power systems are continuously augmented, the stability boundary of the

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power system will be dwindled successively. Therefore, the transient stability improvement is fully considered as one of the most significant power system study.

For this reason, many researchers have been investigated about the transient stability enhancement with control methods and the device implementations. The multi-machine power system stability improvement by the fuzzy wavelet with quantum neuron network based power system stabilizer tuning has been proposed in [1]. The Flexible AC Transmission System (FACT) device has been utilized for damping the inter-area power oscillations and transient stability with the adaptive controller as described in [2]-[7]. Although, adaptive control design methods with FACT devices allow solving the transient stability problem, the fine tuning of the controller is extremely difficult in practical implementation. Therefore, Superconducting Fault Current Limiter (SFCL) is instantly applied for the transient stability improvement and the fault current limitation. The power system stability improvements using the SFCL and the optimal location have been presented in [8]-[11]. Nevertheless, the actual characteristics of SFCL such as the real-time resistance and the recovery time have not been considered on the previous works. To examine this topic, hence, this paper presents the transient stability improvement and fault current reduction considering the recovery time of the Bi-2212 SFCL on SPP.

2. BSCCO SFCL Thermal Model

Thermal subsystem equations of the Bi-2212 SC were investigated in [12] including temperature, heat and electric field characteristics. The coil temperature equation can be expressed as:

$$T = T_a + \frac{1}{C_k}\int_{t_0}^{t}\left[Q_s(t) - Q_r(t)\right] dt \tag{1}$$

$$R_c(t) = \frac{E(t)L_c}{J(t)A_c} \tag{2}$$

Where T_a is the starting temperature (K), C_k is the heat capacity coefficient, Q_s and Q_r are the coil heat energy and the removed heat energy, respectively.

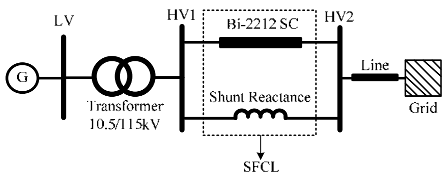

Fig. 1. SPP with Bi-2212 SC single line diagram

3. Simulation Results

The 50-Hz power system with Bi-2212 SFCL is fully implemented on DIgSILENT PowerFactory to investigate the recovery time effect on the transient stability. The disturbance is directly assumed by taking the three-phase fault at HV2 bus for 150 ms of the fault duration. The performance index of the transient stability (J_1) can be written by the following equation, where $\delta(t)$ is the rotor angle (degree), k is a constant gain. The performance index versus the peak fault current is completely illustrated as shown in Fig. 2 by increasing the shunt reactance of the SFCL to demonstrate the recovery time. With a relation from Fig. 2, when the high shunt reactance is established performing as the high recovery, the peak fault current is promptly diminished but the performance index will be raised, which means decreasing the stability margin. With I_{peak} < 32 kA and $J_1 < 8.0$, the selected shunt reactance is about $50\ \Omega$ ($J_1 = 7.0$). The time-domain simulation results of the SPP with the SFCL are investigated with three cases including the low shunt ($20\ \Omega$), the selected shunt ($50\ \Omega$) and the high shunt reactance ($80\ \Omega$), respectively. The resistances of Bi-2212 SC show in Fig. 3 consisting of the system with the high shunt, the low shunt and the selected shunt. Additionally, Fig. 4 also illustrates the current with high, low and selected shunt, respectively.

$$J_1 = \frac{\int \left(\delta(t) - \delta_{ref} \right)^2 dt}{k} \tag{3}$$

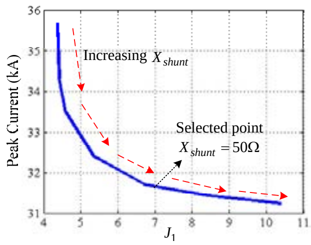

Fig. 2. Peak current versus performance index (J_1) of SPP with the SFCL

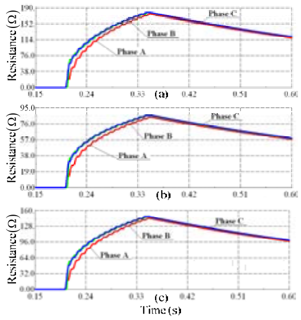

Fig. 3. Bi-2212 SC resistance: (a) high shunt (b) low shunt (c) selected shunt

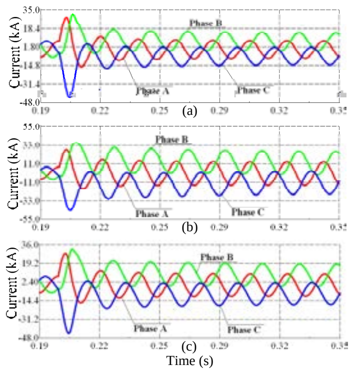

Fig. 4. Generator current: (a) high shunt (b) low shunt (c) selected shunt

The rotor angle for transient stability analysis is illustrated in Fig. 5 comprising with Case A, which shows the selected shunt SFCL unconsidered recovery time. Case B, Case C and Case D demonstrate the SFCL with high, low and selected shunts considered recovery time, respectively. From this result, the transient of the rotor angle with high shunt reactance SFCL instantaneously loses the stability margin decreasing the critical clearing time in comparison with the other cases.

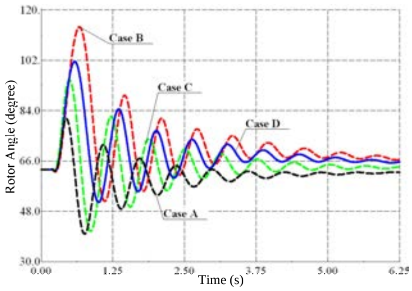

Fig. 5. Generator rotor angle

4. Conclusions

The SPP power system including the Bi-2212 SFCL is totally implemented to evaluate the recovery time on transient stability and fault current reduction. The simulation result shows that the Bi-2212 SFCL with the high shunt reactance has the best effectiveness to abate the peak current. Nevertheless, the stability margin with the high shunt reactance is decreased consequently. On the other hand, with the low shunt reactance, the transient of the rotor angle does not rise quickly but it is not able to cut the first peak current as much as the high shunt implementation. In practical implementation, to achieve both the transient stability and the fault current considered the recovery time, the peak current-performance index relation is completely proposed to find the appropriate shunt reactance. For the future works, unless the cooling system design of the SFCL will be investigated to enhance the recovery time, the fast breaker to bypass the SFCL should be implemented.

Acknowledgement

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